PCT/ZA03/00181

17 DEC 2003

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1) South African Patent Application No. **2003/2585** accompanied by a Provisional Specification was filed at the South African Patent Office on **2 April 2003** in the name of **Rand Afrikaans University** in respect of an invention entitled: **Optical system and method for monitoring variable rotating member"**

2) The photocopy attached hereto is a true copy of the provisional specification and drawings filed with South African Patent Application No. **2003/2585.**

PRIORITY DOCUMENT

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Geteken te Signed at	PRETORIA	in die Republiek van Suid-Afrika, hierdie in the Republic of South Africa, this	10th	dag van day of	December 2003

Registrateur van Patente

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PATENTS ACT, 1978

APPLICATION FOR A PATENT AND ACKNOWLEDGEMENT OF RECEIPT
(Section 30 (1) - Regulation 22)
The grant of a patent is hereby requested by the undermentioned applicant on the basis of the present application filed in duplicate.

OFFICIAL APPLICATION NO			DMK REFERENCE
21	01	2003/2585	P26452ZA00

FULL NAME(S) OF APPLICANT(S)	
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ADDRESS(ES) OF APPLICANT(S)	
	Kingsway & University Road Auckland Park 2006 South Africa

TITLE OF INVENTION			
54	OPTICAL SYSTEM AND METHOD FOR MONITORING VARIABLE ROTATING MEMBER		
	THE APPLICANT CLAIMS PRIORITY AS SET OUT ON THE ACCOMPANING FORM P2 The earliest priority claimed is		
	THIS APPLICATION IS FOR A PATENT OF ADDITION TO PATENT APPLICATION NO.	21	01
	THIS APPLICATION IS FRESH APPLICATION IN TERMS OF SECTION 37 AND BASED ON APPLICATION NO.	21	01

THIS APPLICATION IS ACCOMPANIED BY :

x	1a	A single copy of a provisional specification of 11 pages.
	1b	Two copies of a complete specification of pages.
	2a	Informal drawings of sheets.
x	2b	Formal drawings of 4 sheets.
	3	Publication particulars and abstract (form P8 in duplicate).
	4	A copy of figure of the drawings for the abstract.
	5	Assignment of invention (from the inventors) or other evidence of title.
	6	Certified priority document(s).
	7	Translation of priority document(s).
	8	Assignment of priority rights.
	9	A copy of form P2 and a specification of S.A. Patent Application. 21 01
	10	A declaration and power of attorney on form P3.
	11	Request for ante-dating on form P4.
	12	Request for classification on form P9.
	13a	Request for delay of acceptance on form P4.
	13b	:

DATED 2 April 2003

Patent Attorney for Applicant(s)

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The duplicate will be returned to the applicant's address for service as proof of lodging but is not valid unless endorsed with official stamp.

D. M. Kisch Inc, Sandton

Form P.6

REPUBLIC OF SOUTH AFRICA

PATENTS ACT, 1978

PROVISIONAL SPECIFICATION

(Section 30 (1) - Regulation 27)

OFFICIAL APPLICATION NO.		LODGING DATE		DMK REFERENCE
21	01 2003 / 2585	22	2 April 2003	P26452ZA00

FULL NAME(S) OF APPLICANT(S)	
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FULL NAME(S) OF INVENTOR(S)	
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TITLE OF INVENTION	
54	OPTICAL SYSTEM AND METHOD FOR MONITORING VARIABLE ROTATING MEMBER

INTRODUCTION AND BACKGROUND

This invention relates to a system and method utilizing optical means to measure or monitor variables relating to a rotating member, in use.

It is possible to measure torsion in rotating systems by mechanical strain gauges that are mounted on the rotating member such as a shaft. The mounting angles of the strain gauges on the shaft are chosen such that they measure tensile or compressive strain. However, this system and method require the use of slip rings to transfer electrical signals from the rotating member to a stationary frame of reference. This introduces added complexity, unreliability and electrical noise into the measurements.

One way of measuring torsion without having physical contact with the rotating member is by using surface acoustic waves (SAWs). A SAW device can be rigidly mounted on a flat spot on the member and when the member experiences torque, the torque will stress the sensor and turn it into a wireless, passive, lightweight torque detector. Although this technique does not require slip rings, it is still prone to electrical noise.

Another known system and method measure torsion from a considerable distance from the member by magnetically programming the member and using proprietary circuitry and signal conditioning. The system measures the modifications of the magnetic field generated by the shaft torsion when torque is applied. An important disadvantage of this system is that the member has to be made of a ferromagnetic material with a memory of magnetization.

OBJECT OF THE INVENTION

Accordingly it is an object of the present invention to provide a non-contact system and method for measuring and/or monitoring in use variables relating to a rotating member with which the applicant believes the aforementioned disadvantages may at least be alleviated.

SUMMARY OF THE INVENTION

According to the invention there is provided a system for monitoring a variable relating to a rotating member, the system comprising:

- a source of optical energy for emitting optical energy;
- at least one transducer mountable on the member and which transducer in use modulates received optical energy in accordance with changes in the variable; and

an optical transmission system mountable between the source and the member for transmitting through free space optical energy between the member and the source.

The variable may be any one or more of strain, speed of rotation, temperature at or near the member, torque applied to the member, torsion in the member, bending moment, stress, pressure etc.

The optical source may be mounted on a stationary platform and may comprise a broadband optical source such as a super-luminescent diode or a frequency sweeping narrowband source, coupled to a first length of optical fibre.

The optical transmission system may comprise a first and a second lens, the first lens being mountable on the stationary platform in substantial alignment with the second lens which is mountable on the member. The first and second lenses may comprise a pair of graded-index (GRIN) lenses.

The transducer may comprise a second length of optical fibre and optical energy modulating means connected to the second length of optical fibre.

In a preferred embodiment of the system, the modulating means may comprise a first optical energy reflective element and a spaced second optical energy reflective element. The first and second elements may comprise a first and a second Bragg grating having in wavelength spaced first and second center wavelengths respectively. In other embodiments the modulating means may change the phase of an interferometric signal, or the amplitude of the optical signal.

The first and second gratings may be mounted on the member at ninety degrees relative to one another. In a preferred embodiment the first and second gratings are mounted on the rotating member at forty-five degrees on either side of a longitudinal axis of the member.

Means for separating optical energy propagating away from the source and reflected energy propagating in an opposite direction from the transducer may be provided in the first length of fibre. The separating means may comprise an optical circulator having a first input connected to the source, a second input connected to the first lens and an output.

The output of the circulator may be connected to means sensitive to modulation of the optical energy. Said means may comprise means

sensitive to the modulation in the optical domain, alternatively it may comprise a suitable converter and means sensitive to resulting electrical signals.

The invention further includes within its scope a method of monitoring a variable relating to a rotating member, the method comprising the steps of:

- transmitting optical energy through free space towards the member;
- on the member causing the energy to be modulated in accordance with the parameter to be monitored;
- transmitting from the member and via free space the modulated energy to a stationary platform; and
- analyzing said modulated energy.

BRIEF DESCRIPTION OF THE ACCOMPANYING DIAGRAMS

The invention will now further be described, by way of example only, with reference to the accompanying diagrams wherein

figure 1 is a block diagram of an optical non-contact system according to the invention for monitoring a variable relating to a rotating member;

figure 2	is a diagrammatic representation of the system mounted on a rotary shaft;
figure 3	is a typical spectrum diagram of wavelength separation measured with the system according to the invention and in accordance with the method according to the invention;
figure 4	is spectrum diagram generated in accordance with the method of the invention and illustrating changes in wavelength separation for three different values of torque applied to the shaft; and
figure 5	is a graph illustrating a comparison between theoretical calculated values and measured values of change in wavelength separation against torque.

DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

A system according to the invention for monitoring in a non-contact arrangement certain variables relating to a rotating member in use, is generally designated by the reference numeral 10 in figures 1 and 2.

The rotating member may for example be an elongate shaft 12 mounted for rotation about a longitudinal axis 14 thereof.

The system comprises an optical source 16 mounted on stationary platform 18. The optical source 16 may be a broadband source such as super-luminescent diode (SLD), alternatively it may be a sweeping narrowband source (not shown). The diode is coupled to a first length 20 of optical fibre and the first length of optical fibre is connected to a first input 22 of optical energy separating means, such as a circulator 24. A second input 26 of the circulator is connected via fibre 28 to a first lens 30 of an optical energy transmission system 32. An output 34 of the circulator is connectable to a known optical spectrum analyzer 36.

The system further comprises a transducer 38 mounted on the shaft and which transducer in use modulates optical energy received in accordance with changes in the variable to be monitored. The transducer comprises a second length 40 of optical fibre and two frequency sensitive optical reflector elements connected in the fibre. The two elements may comprise a first Bragg grating 42 having a first center wavelength and a second Bragg grating 44 having a second and different center wavelength. As best shown in figure 2, the gratings are preferably mounted at a right angle relative to one another, and each at an angle of about 45 degrees relative to the longitudinal axis 14 of the shaft 12. The second length of fibre 40 is connected at one

end thereof to a second lens 46 of the aforementioned transmission system 32. The transmission system 32 transmits optical energy through free space 48 between the platform 18 and the rotating member 12 as will hereinafter be described.

A more detailed diagram of the system 10 as used in conjunction with a shaft 12 is shown in figure 2. Like reference numerals are used to designate like parts. Gratings 42 and 44 in fibre 40 are fixed to shaft 12. Second lens 46 is centrally mounted in a circular disc 50 mounted at one end of a tube 52. At the other end of the tube there is provided a ball bearing arrangement 54 comprising a stationary inner ring 56 and a rotary outer ring 58 separated by balls 60 in known manner. First lens 30 is centrally mounted in the inner ring 56 to be substantially axially in line with the second lens 46. A flexible bellows member 62 is provided drivingly to connect the tube 52 to the shaft 12.

Optical energy propagates from source 16 in a first direction via circulator 24, lens 30, free space 48, lens 46 and optical fibre 40. Light of a first wavelength is reflected by grating 42 to propagate in the opposite direction. Light of a second wavelength is similarly reflected by grating 44. The values of the wavelengths are

proportional to the strain in the shaft. The reflected energy is separated from the energy propagating in the first direction by the circulator 24. The reflected energy is directed to the analyzer 36.

A typical diagram of reflected energy against wavelength obtained from analyzer 36 is shown 64 in figure 3. Energy reflected by grating 42 is shown at 66 in figure 3 and energy reflected by grating 44 is shown at 68. There is a spacing or difference 70 between the wavelengths 66 and 68.

In figure 4 there is shown a diagram corresponding to the diagram in figure 3, but for three different values of torque applied to the shaft. A first diagram for no torque applied to the shaft has a first difference 70 is shown at 72. With torque of 40 Nm applied to the shaft, the difference between the wavelengths changes to a value 76 and for torque of 95 Nm, the difference increases to a value 78.

It has been found that the difference in wavelength between the reflected signals is proportional to the torsion and that a change in the mean value of the wavelengths is proportional to the temperature of the gratings and hence the shaft or a region about the shaft. Because the measurement system and method enable one to separate strain

and temperature effects it is possible to compensate for temperature variations and to measure any one or more of temperature, torque, strain, stress, bending movement, pressure.

Amplitude modulation introduced to the signals by slight misalignment of the lenses 30 and 46 carries information regarding speed of rotation of the rotating shaft.

In figure 5 there is illustrated with squares measured values in wavelength difference against applied torque for comparison with theoretically computed values which are shown with a straight solid line.

It will be appreciated that there are many variations in detail on the system and method according to the invention without departing from the scope and spirit of this disclosure.

Dated this 2 day of April 2003

Patent Attorney / Agent for the Applicant

2003/2585

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4 SHEETS
SHEET 1

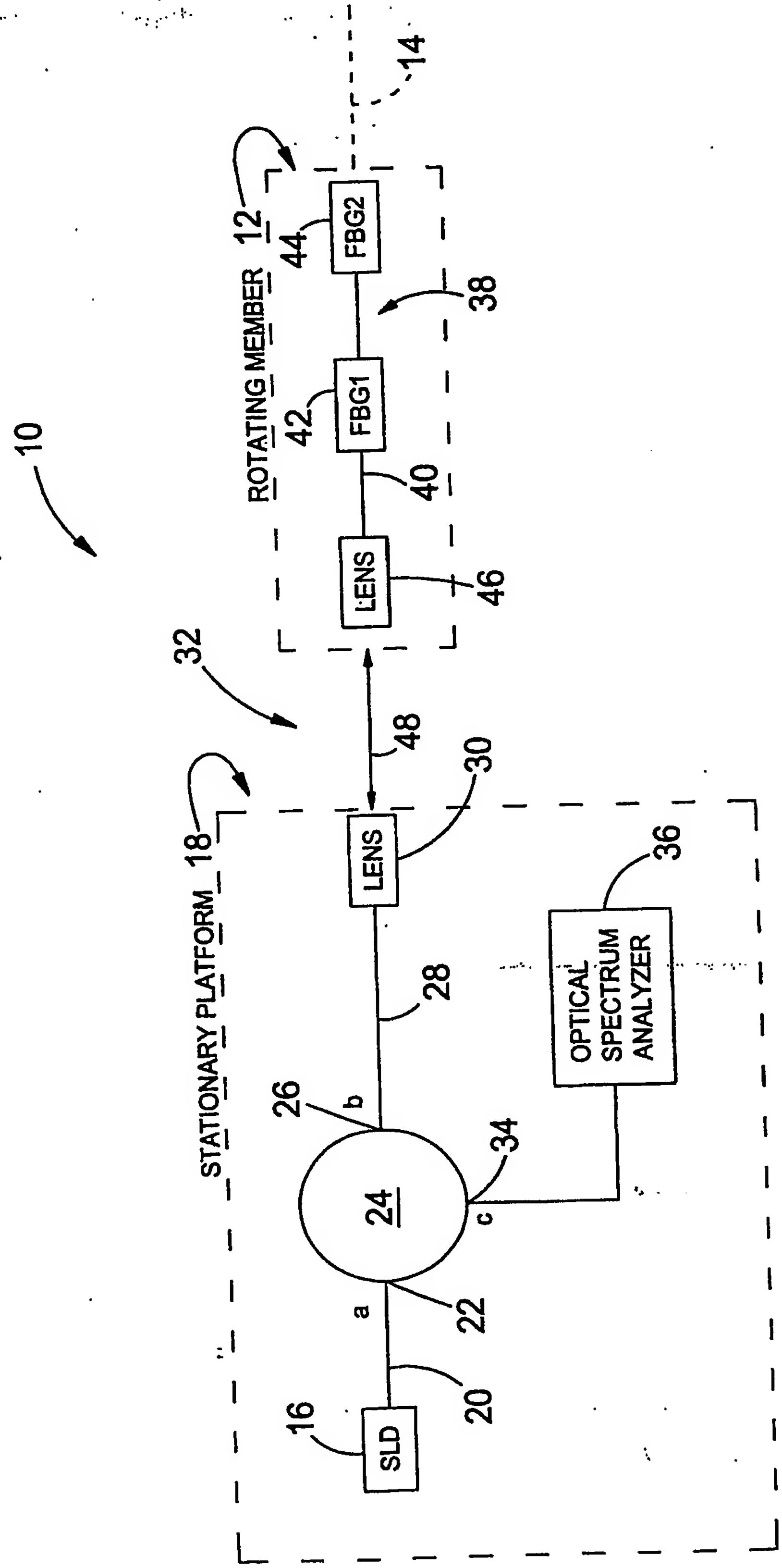

FIGURE 1

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SHEET 2

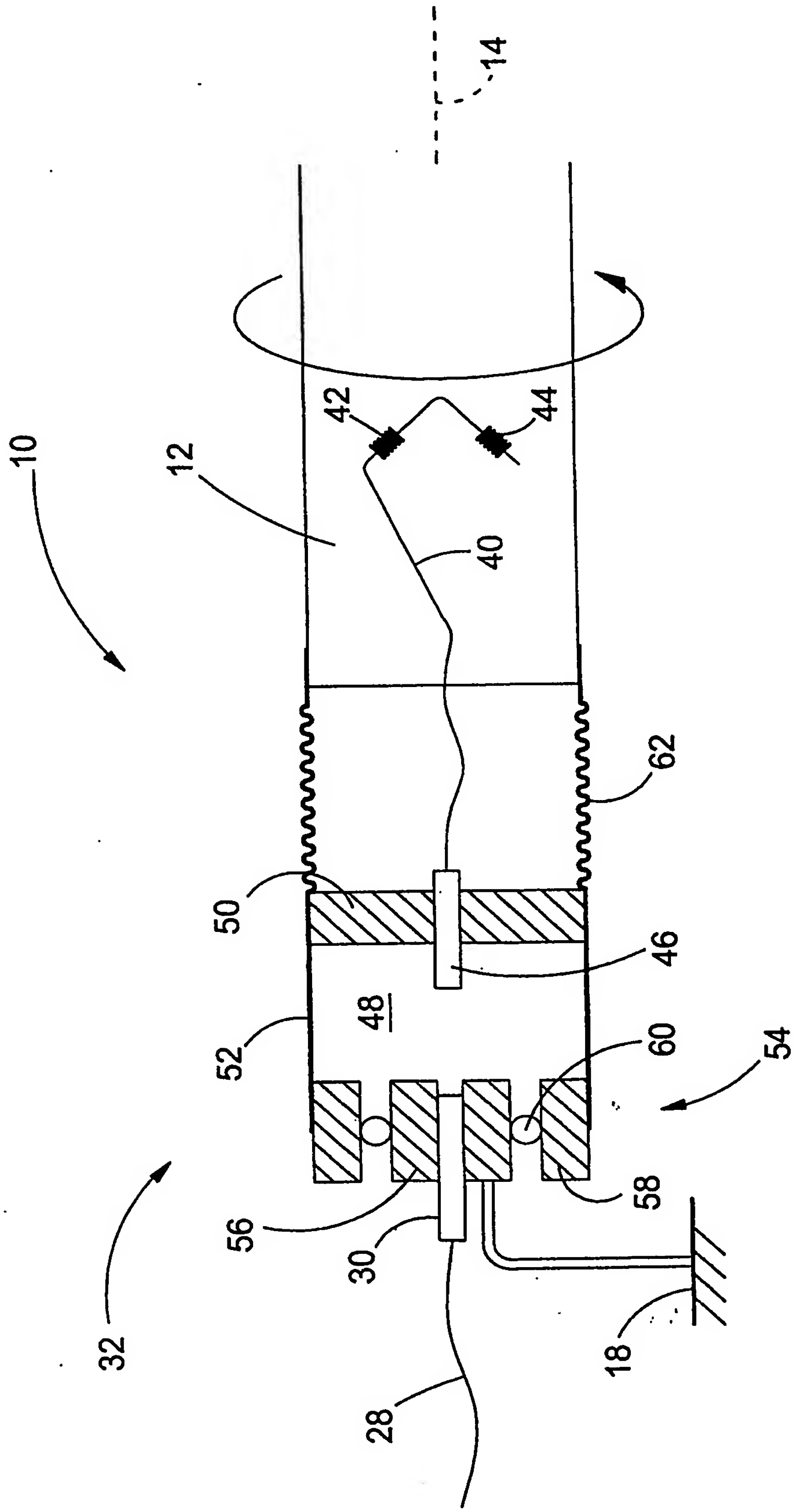

FIGURE 2

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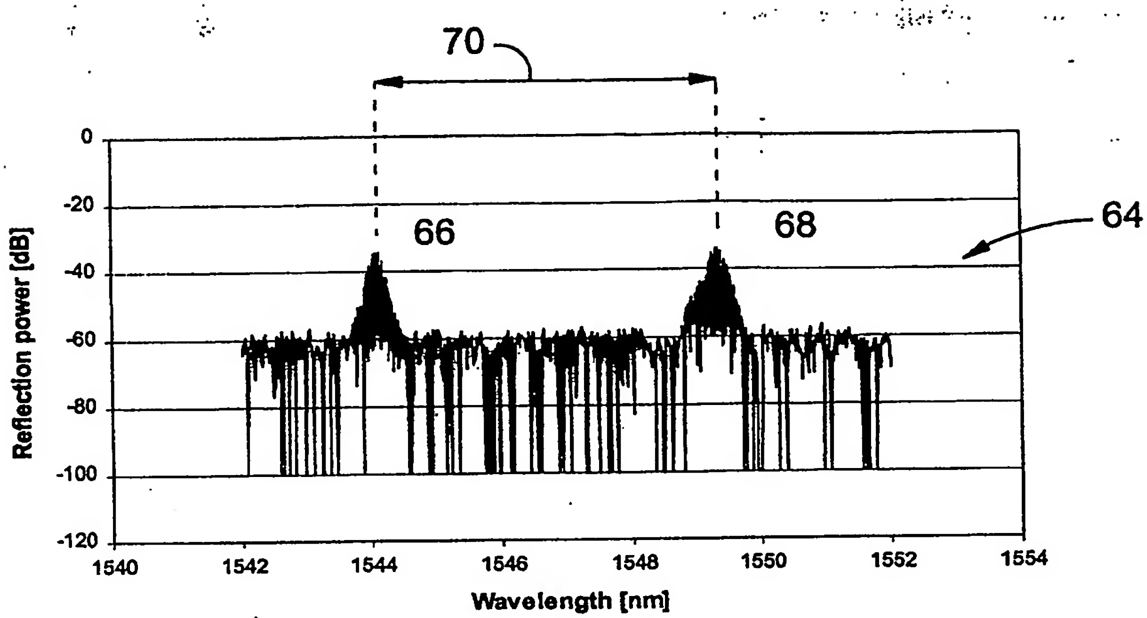

FIGURE 3

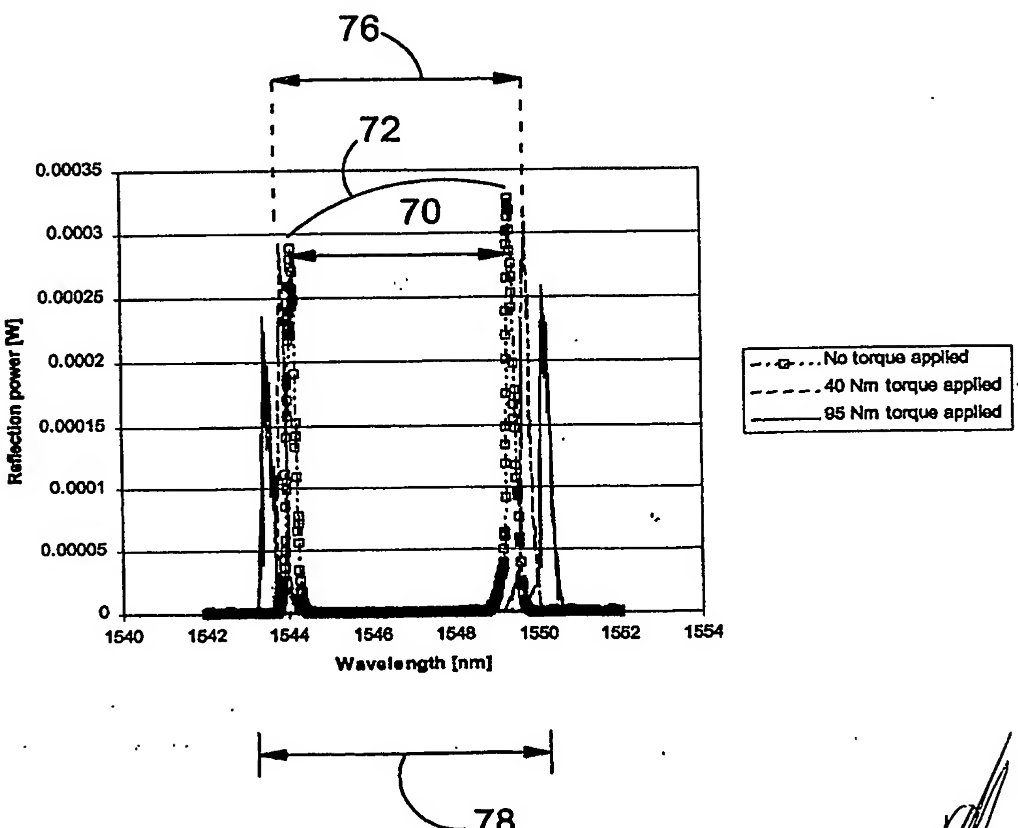

FIGURE 4

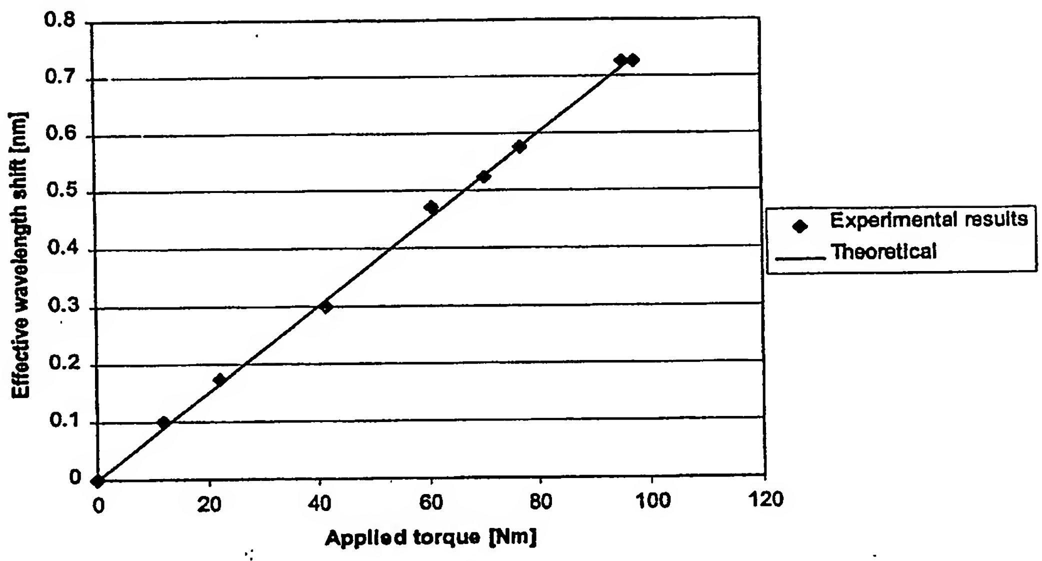
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Effective wavelength shift [nm]
0
20
40
60
80
100
120
Applied torque [Nm]
Experimental results
Theoretical

FIGURE 5